

Moduli stabilization and F-term uplifting in semi-realistic magnetized orbifold models

Hiroyuki Abe (Waseda U.)

String Phenomenology 2018
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This talk is mainly based on

T. Kobayashi, K. Sumita & H. A.,

Dynamical supersymmetry breaking on magnetized tori and orbifolds,
Nucl.Phys. B911 (2016) 606, arXiv:1605.02922 [hep-th]

T. Kobayashi, K. Sumita, S. Uemura & H. A.,

Kähler moduli stabilization in semi-realistic magnetized orbifold models,
Phys.Rev. D96 (2017) 026019, arXiv:1703.03402 [hep-th]

T. Kobayashi, K. Sumita, S. Uemura & H. A., to appear

in collaboration with

Tatsuo Kobayashi (Hokkaido U.)

Keigo Sumita (Waseda U.)

Shohei Uemura (Kyoto Sangyo U.)

MAGNETIZED ORBIFOLD MODEL

SYM on magnetized tori

Basic features

- Partial breaking of SUSY and gauge symmetries
- Degenerate chiral zero-modes appear
- The degeneracy is determined by the number of fluxes they feel
- Analytic forms of wavefunctions \rightarrow 4D Yukawa couplings

D. Cremades, L.E. Ibanez & F. Marchesano, JHEP 0405 (2004) 079

Applications

- (MS)SM-like models, dynamical SUSY breaking (DSB), ...

Further aspects

- D-brane interpretations, dual descriptions, ...

MSSM-LIKE MODELS (VISIBLE SECTOR)

10D $U(8)$ SYM on magnetized $(T^2)^3$

T. Kobayashi, H. Ohki, K. Sumita & H. A., NPB 863 (2012) 1

Magnetic fluxes $U(8) \rightarrow U(4)_C \times U(2)_L \times U(2)_R$

$$F_{2+2r, 3+2r} = 2\pi \begin{pmatrix} M_C^{(r)} \mathbf{1}_4 & & \\ & M_L^{(r)} \mathbf{1}_2 & \\ & & M_R^{(r)} \mathbf{1}_2 \end{pmatrix} \quad r = 1, 2, 3$$

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Wilson-lines $\rightarrow U(3)_C \times U(2)_L \times U(1)_{C'} \times U(1)_{R'} \times U(1)_{R''}$

$$\zeta_r = \begin{pmatrix} \zeta_C^{(r)} \mathbf{1}_3 & & & & \\ & \zeta_{C'}^{(r)} & & & \\ & & \zeta_L^{(r)} \mathbf{1}_2 & & \\ & & & \zeta_{R'}^{(r)} & \\ & & & & \zeta_{R''}^{(r)} \end{pmatrix}$$

10D $U(8)$ SYM on magnetized $(T^2)^3$

T. Kobayashi, H. Ohki, K. Sumita & H. A., NPB 863 (2012) 1

Flux ansatz

$$(M_C^{(1)}, M_L^{(1)}, M_R^{(1)}) = (0, +3, -3),$$

$$(M_C^{(2)}, M_L^{(2)}, M_R^{(2)}) = (0, -1, 0),$$

$$(M_C^{(3)}, M_L^{(3)}, M_R^{(3)}) = (0, 0, +1),$$



Three generations of
quarks and leptons and
six generations of Higgs

10D $U(8)$ SYM on magnetized $(T^2)^3$

T. Kobayashi, H. Ohki, K. Sumita & H. A., NPB 863 (2012) 1

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$$(M_C^{(3)}, M_L^{(3)}, M_R^{(3)}) = (0, 0, +1),$$



Three generations of
quarks and leptons and
six generations of Higgs

D -flat condition: $\frac{1}{\mathcal{A}^{(1)}} M_a^{(1)} + \frac{1}{\mathcal{A}^{(2)}} M_a^{(2)} + \frac{1}{\mathcal{A}^{(3)}} M_a^{(3)} = 0$

$$\Leftrightarrow \mathcal{A}^{(1)}/\mathcal{A}^{(2)} = \mathcal{A}^{(1)}/\mathcal{A}^{(3)} = 3$$

10D $U(8)$ SYM on magnetized $(T^2)^3$

T. Kobayashi, H. Ohki, A. Oikawa, K. Sumita & H. A., NPB 870 (2013) 30

Zero-modes in adjoint chiral multiplets ϕ_i

$$\begin{aligned} \phi_1^{\mathcal{I}_{ab}} &= \left(\begin{array}{cc|c|cc} \Omega_C^{(1)} & \Xi_{CC'}^{(1)} & 0 & \Xi_{CR'}^{(1)} & \Xi_{CR''}^{(1)} \\ \Xi_{C'C}^{(1)} & \Omega_{C'}^{(1)} & 0 & \Xi_{C'R'}^{(1)} & \Xi_{C'R''}^{(1)} \\ \hline \Xi_{LC}^{(1)} & \Xi_{LC'}^{(1)} & \Omega_L^{(1)} & H_u^K & H_d^K \\ 0 & 0 & 0 & \Omega_{R'}^{(1)} & \Xi_{R'R''}^{(1)} \\ 0 & 0 & 0 & \Xi_{R''R'}^{(1)} & \Omega_{R''}^{(1)} \end{array} \right) \quad \phi_2^{\mathcal{I}_{ab}} = \left(\begin{array}{cc|c|cc} \Omega_C^{(2)} & \Xi_{CC'}^{(2)} & Q^I & 0 & 0 \\ \Xi_{C'C}^{(2)} & \Omega_{C'}^{(2)} & L^I & 0 & 0 \\ \hline 0 & 0 & \Omega_L^{(2)} & 0 & 0 \\ 0 & 0 & 0 & \Omega_{R'}^{(2)} & \Xi_{R'R''}^{(2)} \\ 0 & 0 & 0 & \Xi_{R''R'}^{(2)} & \Omega_{R''}^{(2)} \end{array} \right) \\ \phi_3^{\mathcal{I}_{ab}} &= \left(\begin{array}{cc|c|cc} \Omega_C^{(3)} & \Xi_{CC'}^{(3)} & 0 & 0 & 0 \\ \Xi_{C'C}^{(3)} & \Omega_{C'}^{(3)} & 0 & 0 & 0 \\ \hline 0 & 0 & \Omega_L^{(3)} & 0 & 0 \\ \hline U^J & N^J & 0 & \Omega_{R'}^{(3)} & \Xi_{R'R''}^{(3)} \\ D^J & E^J & 0 & \Xi_{R''R'}^{(3)} & \Omega_{R''}^{(3)} \end{array} \right) \end{aligned}$$

Matter zero-modes on magnetized $(T^2)^3$

T. Kobayashi, H. Ohki, A. Oikawa, K. Sumita & H. A., NPB 870 (2013) 30

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T. Kobayashi, H. Ohki, A. Oikawa, K. Sumita & H. A., NPB 870 (2013) 30

Zero-modes in adjoint chiral multiplets ϕ_i

Six generations of Higgs ($K = 1, 2, \dots, 6$)

$$\phi_1^{\mathcal{I}_{ab}} = \left(\begin{array}{cc|c|cc} \Omega_C^{(1)} & \Xi_{CC'}^{(1)} & 0 & \Xi_{CR'}^{(1)} & \Xi_{CR''}^{(1)} \\ \Xi_{C'C}^{(1)} & \Omega_{C'}^{(1)} & 0 & \Xi_{C'R'}^{(1)} & \Xi_{C'R''}^{(1)} \\ \hline \Xi_{LC}^{(1)} & \Xi_{LC'}^{(1)} & \Omega_L^{(1)} & H_u^K & H_d^K \\ 0 & 0 & 0 & \Omega_{R'}^{(1)} & \Xi_{R'R''}^{(1)} \\ 0 & 0 & 0 & \Xi_{R''R'}^{(1)} & \Omega_{R''}^{(1)} \end{array} \right)$$

$$\phi_2^{\mathcal{I}_{ab}} = \left(\begin{array}{cc|c|cc} \Omega_C^{(2)} & \Xi_{CC'}^{(2)} & Q^I & 0 & 0 \\ \Xi_{C'C}^{(2)} & \Omega_{C'}^{(2)} & L^I & 0 & 0 \\ \hline 0 & 0 & \Omega_L^{(2)} & 0 & 0 \\ 0 & 0 & 0 & \Omega_{R'}^{(2)} & \Xi_{R'R''}^{(2)} \\ 0 & 0 & 0 & \Xi_{R''R'}^{(2)} & \Omega_{R''}^{(2)} \end{array} \right)$$

$$\phi_3^{\mathcal{I}_{ab}} = \left(\begin{array}{cc|c|cc} \Omega_C^{(3)} & \Xi_{CC'}^{(3)} & 0 & 0 & 0 \\ \Xi_{C'C}^{(3)} & \Omega_{C'}^{(3)} & 0 & 0 & 0 \\ \hline 0 & 0 & \Omega_L^{(3)} & 0 & 0 \\ \boxed{U^J} & \boxed{N^J} & 0 & \Omega_{R'}^{(3)} & \Xi_{R'R''}^{(3)} \\ \boxed{D^J} & \boxed{E^J} & 0 & \Xi_{R''R'}^{(3)} & \Omega_{R''}^{(3)} \end{array} \right)$$

Three generations of right-handed quarks and leptons ($J = 1, 2, 3$)

Three generations of left-handed quarks and leptons ($I = 1, 2, 3$)

Matter zero-modes on magnetized $(T^2)^3/Z_2$

T. Kobayashi, H. Ohki, A. Oikawa, K. Sumita & H. A., NPB 870 (2013) 30

Zero-modes in adjoint chiral multiplets ϕ_i

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$$\phi_2^{\mathcal{I}_{ab}} = \left(\begin{array}{cc|c|cc} \Omega_C^{(2)} & \Xi_{CC'}^{(2)} & Q^I & 0 & 0 \\ \Xi_{C'C}^{(2)} & \Xi_{LC'}^{(2)} & L^I & 0 & 0 \\ \hline 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & \Omega_{R'}^{(2)} & \Xi_{R'R''}^{(2)} \\ 0 & 0 & 0 & \Xi_{R''R'}^{(2)} & \Omega_{R''}^{(2)} \end{array} \right)$$

$$\phi_3^{\mathcal{I}_{ab}} = \left(\begin{array}{cc|c|cc} \Omega_C^{(3)} & \Xi_{CC'}^{(3)} & 0 & 0 & 0 \\ \Xi_{C'C}^{(3)} & \Omega_{C'}^{(3)} & 0 & 0 & 0 \\ \hline 0 & 0 & 0 & 0 & 0 \\ \boxed{U^J \quad N^J} & \boxed{D^J \quad E^J} & 0 & \Omega_{R'}^{(3)} & \Xi_{R'R''}^{(3)} \\ 0 & 0 & 0 & \Xi_{R''R'}^{(3)} & \Omega_{R''}^{(3)} \end{array} \right)$$

Three generations of right-handed quarks and leptons ($J = 1, 2, 3$)

Three generations of left-handed quarks and leptons ($I = 1, 2, 3$)

on orbifold $(T^2)^3/Z_2$

$$P = \begin{pmatrix} -\mathbf{1}_4 & & \\ & +\mathbf{1}_2 & \\ & & +\mathbf{1}_2 \end{pmatrix}$$

$$Z_2: (z_1, z_2, z_3) \rightarrow (z_1, -z_2, -z_3)$$

Matter zero-modes on magnetized $(T^2)^3/Z_2$

T. Kobayashi, H. Ohki, A. Oikawa, K. Sumita & H. A., NPB 870 (2013) 30

Zero-modes in ϕ_i on orbifold $(T^2)^3/Z_2$

$$\phi_1^{\mathcal{I}^{ab}} = \left(\begin{array}{cc|c|cc} \Omega_C^{(1)} & \Xi_{CC'}^{(1)} & 0 & 0 & 0 \\ \Xi_{C'C}^{(1)} & \Omega_{C'}^{(1)} & 0 & 0 & 0 \\ \hline 0 & 0 & \Omega_L^{(1)} & \boxed{H_u^K} & \boxed{H_d^K} \\ 0 & 0 & 0 & \Omega_{R'}^{(1)} & \Xi_{R'R''}^{(1)} \\ 0 & 0 & 0 & \Xi_{R''R'}^{(1)} & \Omega_{R''}^{(1)} \end{array} \right) \quad \phi_2^{\mathcal{I}^{ab}} = \left(\begin{array}{cc|c|cc} 0 & 0 & Q^I & 0 & 0 \\ 0 & 0 & L^I & 0 & 0 \\ \hline 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \end{array} \right)$$

$$\phi_3^{\mathcal{I}^{ab}} = \left(\begin{array}{cc|c|cc} 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ \hline 0 & 0 & 0 & 0 & 0 \\ \boxed{U^J} & \boxed{N^J} & 0 & 0 & 0 \\ \boxed{D^J} & \boxed{E^J} & 0 & 0 & 0 \end{array} \right)$$

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$$\phi_3^{\mathcal{I}^{ab}} = \left(\begin{array}{cc|c|cc} 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ \hline 0 & 0 & 0 & 0 & 0 \\ \hline U^J & N^J & 0 & 0 & 0 \\ D^J & E^J & 0 & 0 & 0 \end{array} \right)$$

- Overlap integrals of wavefunctions \rightarrow 4D Yukawa couplings
- Nonperturbative effects may yield μ -terms for multi-Higgs
(Localized μ -terms at orbifold fixed points will be discussed by the next speaker)

Flavor structure on magnetized $(T^2)^3/Z_2$

T. Kobayashi, H. Ohki, A. Oikawa, K. Sumita & H. A., NPB 870 (2013) 30

	Sample values	Observed	
(m_u, m_c, m_t)	$(3.1 \times 10^{-3}, 1.01, 1.70 \times 10^2)$	$(2.3 \times 10^{-3}, 1.28, 1.74 \times 10^2)$	(GeV)
(m_d, m_s, m_b)	$(2.8 \times 10^{-3}, 1.48 \times 10^{-1}, 6.46)$	$(4.8 \times 10^{-3}, 0.95 \times 10^{-1}, 4.18)$	(GeV)
(m_e, m_μ, m_τ)	$(4.68 \times 10^{-4}, 5.76 \times 10^{-2}, 3.31)$	$(5.11 \times 10^{-4}, 1.06 \times 10^{-1}, 1.78)$	(GeV)
$ V_{CKM} $	$\begin{pmatrix} 0.98 & 0.21 & 0.0023 \\ 0.21 & 0.98 & 0.041 \\ 0.011 & 0.040 & 1.0 \end{pmatrix}$	$\begin{pmatrix} 0.97 & 0.23 & 0.0035 \\ 0.23 & 0.97 & 0.041 \\ 0.0087 & 0.040 & 1.0 \end{pmatrix}$	
	Sample values	Observed	
$(m_{\nu_1}, m_{\nu_2}, m_{\nu_3})$	$(3.6 \times 10^{-19}, 8.8 \times 10^{-12}, 2.7 \times 10^{-11})$	$< 2 \times 10^{-9}$	(GeV)
$ m_{\nu_1}^2 - m_{\nu_2}^2 $	7.67×10^{-23}	7.50×10^{-23}	(GeV) ²
$ m_{\nu_1}^2 - m_{\nu_3}^2 $	7.12×10^{-22}	2.32×10^{-21}	(GeV) ²
$ V_{PMNS} $	$\begin{pmatrix} 0.85 & 0.46 & 0.25 \\ 0.50 & 0.59 & 0.63 \\ 0.15 & 0.66 & 0.73 \end{pmatrix}$	$\begin{pmatrix} 0.82 & 0.55 & 0.16 \\ 0.51 & 0.58 & 0.64 \\ 0.26 & 0.61 & 0.75 \end{pmatrix}$	

Particle Data Group Collaboration (Beringer, J. et al.), PRD 86 (2012) 010001

A semi-realistic pattern from non-hierarchical parameters

DSB MODELS (HIDDEN SECTOR)

Hidden sector models

- Magnetized SYM in higher-dim.
 - 4D chiral gauge theories with flavors
 - will be applied to
 - not only the visible ((MS)SM) sector
 - but also the hidden (DSB or moduli stabilization) sectors

10D $U(N)$ SYM model on $(T^2)^3$

T. Kobayashi, K. Sumita & H. A., NPB 911 (2016) 606

Fluxes leading to $U(N) \rightarrow U(N_C) \times U(N_X) \times U(N_Y)$

$$M^{(1)} = \begin{pmatrix} 0 & 0 & 0 \\ 0 & M & 0 \\ 0 & 0 & M \end{pmatrix}, \quad M^{(2)} = \begin{pmatrix} 0 & 0 & 0 \\ 0 & -1 & 0 \\ 0 & 0 & 0 \end{pmatrix}, \quad M^{(3)} = \begin{pmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & -1 \end{pmatrix}$$

Zero-modes in ϕ_i

$$\phi_1 = \begin{pmatrix} \Xi_1 & 0 & 0 \\ \tilde{Q}' & \Xi'_1 & 0 \\ Q & 0 & \Xi''_1 \end{pmatrix}, \quad \phi_2 = \begin{pmatrix} \Xi_2 & \tilde{Q} & 0 \\ 0 & \Xi'_2 & 0 \\ 0 & S' & \Xi''_2 \end{pmatrix}, \quad \phi_3 = \begin{pmatrix} \Xi_3 & 0 & Q' \\ 0 & \Xi'_3 & S \\ 0 & 0 & \Xi''_3 \end{pmatrix}$$

10D $U(N)$ SYM model on $(T^2)^3/(Z_2 \times Z_2')$

T. Kobayashi, K. Sumita & H. A., NPB 911 (2016) 606

Fluxes leading to $U(N) \rightarrow U(N_C) \times U(N_X) \times U(N_Y)$

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Zero-modes in ϕ_i

$$\phi_1 = \begin{pmatrix} \Sigma & 0 & 0 \\ \tilde{Q} & \Sigma & 0 \\ Q & 0 & \Sigma \end{pmatrix}, \quad \phi_2 = \begin{pmatrix} \Sigma & \tilde{Q} & 0 \\ 0 & \Sigma & 0 \\ 0 & \tilde{Q} & \Sigma \end{pmatrix}, \quad \phi_3 = \begin{pmatrix} \Sigma & 0 & \tilde{Q} \\ 0 & \Sigma & S \\ 0 & 0 & \Sigma \end{pmatrix}$$

$$\begin{aligned} Z_2 &: (z_1, z_2, z_3) \rightarrow (-z_1, -z_2, z_3) \\ Z'_2 &: (z_1, z_2, z_3) \rightarrow (z_1, -z_2, -z_3) \end{aligned}$$

$$P = \begin{pmatrix} +1 & & \\ & -1 & \\ & & +1 \end{pmatrix} \quad P' = \begin{pmatrix} +1 & & \\ & -1 & \\ & & -1 \end{pmatrix}$$

10D $U(N)$ SYM model on $(T^2)^3/(Z_2 \times Z_2')$

T. Kobayashi, K. Sumita & H. A., NPB 911 (2016) 606

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Zero-modes in ϕ_i

$$\phi_1 = \begin{pmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ Q & 0 & 0 \end{pmatrix}, \quad \phi_2 = \begin{pmatrix} 0 & \tilde{Q} & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{pmatrix}, \quad \phi_3 = \begin{pmatrix} 0 & 0 & 0 \\ 0 & 0 & S \\ 0 & 0 & 0 \end{pmatrix}$$

10D $U(N)$ SYM model on $(T^2)^3/(Z_2 \times Z_2')$

T. Kobayashi, K. Sumita & H. A., NPB 911 (2016) 606

Fluxes leading to $U(N) \rightarrow U(N_C) \times U(N_X) \times U(N_Y)$

$$M^{(1)} = \begin{pmatrix} 0 & 0 & 0 \\ 0 & M & 0 \\ 0 & 0 & M \end{pmatrix}, \quad M^{(2)} = \begin{pmatrix} 0 & 0 & 0 \\ 0 & -1 & 0 \\ 0 & 0 & 0 \end{pmatrix}, \quad M^{(3)} = \begin{pmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & -1 \end{pmatrix}$$

Zero-modes in ϕ_i

$$\phi_1 = \begin{pmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ Q & 0 & 0 \end{pmatrix}, \quad \phi_2 = \begin{pmatrix} 0 & \tilde{Q} & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{pmatrix}, \quad \phi_3 = \begin{pmatrix} 0 & 0 & 0 \\ 0 & 0 & S \\ 0 & 0 & 0 \end{pmatrix}$$

Superpotential

$$W = SQ\tilde{Q}$$

10D $U(N)$ SYM model on $(T^2)^3/(Z_2 \times Z_2')$

T. Kobayashi, K. Sumita & H. A., NPB 911 (2016) 606

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$$M^{(1)} = \begin{pmatrix} 0 & 0 & 0 \\ 0 & M & 0 \\ 0 & 0 & M \end{pmatrix}, \quad M^{(2)} = \begin{pmatrix} 0 & 0 & 0 \\ 0 & -1 & 0 \\ 0 & 0 & 0 \end{pmatrix}, \quad M^{(3)} = \begin{pmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & -1 \end{pmatrix}$$

Zero-modes in $\phi_i \rightarrow U(N_C)$ SYM with N_F flavors Q, \tilde{Q}

$$\phi_1 = \begin{pmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ Q & 0 & 0 \end{pmatrix}, \quad \phi_2 = \begin{pmatrix} 0 & \tilde{Q} & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{pmatrix}, \quad \phi_3 = \begin{pmatrix} 0 & 0 & 0 \\ 0 & 0 & S \\ 0 & 0 & 0 \end{pmatrix}$$

Superpotential

$$W = S Q \tilde{Q}$$

10D $U(N)$ SYM model on $(T^2)^3/(Z_2 \times Z_2')$

T. Kobayashi, K. Sumita & H. A., NPB 911 (2016) 606

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$$M^{(1)} = \begin{pmatrix} 0 & 0 & 0 \\ 0 & M & 0 \\ 0 & 0 & M \end{pmatrix}, \quad M^{(2)} = \begin{pmatrix} 0 & 0 & 0 \\ 0 & -1 & 0 \\ 0 & 0 & 0 \end{pmatrix}, \quad M^{(3)} = \begin{pmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & -1 \end{pmatrix}$$

Zero-modes in $\phi_i \rightarrow U(N_C)$ SYM with N_F flavors Q, \tilde{Q}

$$\phi_1 = \begin{pmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ Q & 0 & 0 \end{pmatrix}, \quad \phi_2 = \begin{pmatrix} 0 & \tilde{Q} & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{pmatrix}, \quad \phi_3 = \begin{pmatrix} 0 & 0 & 0 \\ 0 & 0 & S \\ 0 & 0 & 0 \end{pmatrix}$$

Superpotential for $N_C > N_F$

$$W = S Q \tilde{Q} + C_{N_C, N_F} \left(\frac{\Lambda^{3N_C - N_F}}{\det Q \tilde{Q}} \right)^{1/(N_C - N_F)} \rightarrow \text{Dynamical SUSY breaking (DSB)}$$

COMBINING VISIBLE & HIDDEN SECTORS

Combining visible & hidden sectors

Realize the (essential parts of) previous two sectors in a single system

To avoid the appearance of unwanted (chiral) exotic modes

→ D7-brane configurations

Configurations of D7-branes

T. Kobayashi, K. Sumita, S. Uemura & H. A., to appear

Configurations of D7-branes

		G	T^2	T^2	T^2	Z_2	Z'_2
MSSM	$D7_A$	$U(4)_A$	✓	✗	✓	$P_A = +\mathbf{1}_4$	$P'_A = +\mathbf{1}_4$
	$D7_B$	$U(4)_B$	✓	✓	✗	$P_B = -\mathbf{1}_4$	$P'_B = -\mathbf{1}_4$
DSB	$D7_C$	$U(1)_C$	✓	✗	✓	$P_C = +1$	$P'_C = -1$
	$D7_D$	$U(N+1)_D$	✓	✓	✗	$P_D = +\mathbf{1}_4$	$P'_D = +\mathbf{1}_4$

	$ M $	0	1	2	3	4	5	$2n$	$2n+1$
Even	1	1	2	2	3	3	$n+1$	$n+1$	
Odd	0	0	0	1	1	2	$n-1$	n	

Visible (MSSM) sector

T. Kobayashi, K. Sumita, S. Uemura & H. A., PRD96 (2017) 026019

Fluxes leading to $U(4)_A \rightarrow U(3)_C \times U(1)_\ell$
 $U(4)_B \rightarrow U(2)_L \times U(2)_R$

$$M_A^{(1)} = \begin{pmatrix} -4 \times \mathbf{1}_3 & 0 \\ 0 & -5 \times \mathbf{1}_1 \end{pmatrix}, \quad M_A^{(3)} = \begin{pmatrix} 4 \times \mathbf{1}_3 & 0 \\ 0 & 5 \times \mathbf{1}_1 \end{pmatrix}$$
$$M_B^{(1)} = \begin{pmatrix} -12 \times \mathbf{1}_2 & 0 \\ 0 & 0 \times \mathbf{1}_2 \end{pmatrix}, \quad M_B^{(2)} = \begin{pmatrix} 1 \times \mathbf{1}_2 & 0 \\ 0 & 0 \times \mathbf{1}_2 \end{pmatrix}$$

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Zero-modes 3-gens of quarks & leptons, 5-gens of Higgs

$$\Phi_1^B = \begin{pmatrix} 0 & 0 \\ H & 0 \end{pmatrix}, \quad \Phi_2^{AB} = \begin{pmatrix} 0 & Q_R \\ 0 & L_R \end{pmatrix}, \quad \Phi_3^{BA} = \begin{pmatrix} Q_L & L_L \\ 0 & 0 \end{pmatrix}$$
$$\Phi_1^A = \Phi_2^A = \Phi_3^A = \Phi_2^B = \Phi_3^B = 0$$

Hidden (DSB) sector

T. Kobayashi, K. Sumita, S. Uemura & H. A., to appear

Fluxes leading to $U(N+1)_D \rightarrow U(N) \times U(1)$

$$M_C^{(1)} = 0 \quad , M_C^{(3)} = 0,$$
$$M_D^{(1)} = \begin{pmatrix} 12 \times \mathbf{1}_N & 0 \\ 0 & 0 \end{pmatrix}, \quad M_D^{(2)} = \begin{pmatrix} -1 \times \mathbf{1}_N & 0 \\ 0 & 0 \end{pmatrix}$$

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Zero-modes

$\Phi_1^C, \Phi_2^C, \Phi_3^C, \Phi_2^D$, and Φ_3^D , have no zero-modes

$$\Phi_1^D = \begin{pmatrix} 0 & \tilde{Q}_N \\ 0 & 0 \end{pmatrix}, \quad \Phi_2^{CD} = (Q_N, 0), \quad \Phi_3^{DC} = \begin{pmatrix} 0 \\ \tilde{X} \end{pmatrix}$$

$N_f = 5$ pairs of (\tilde{Q}_N, Q_N) appear

Hidden (DSB) sector

T. Kobayashi, K. Sumita, S. Uemura & H. A., to appear

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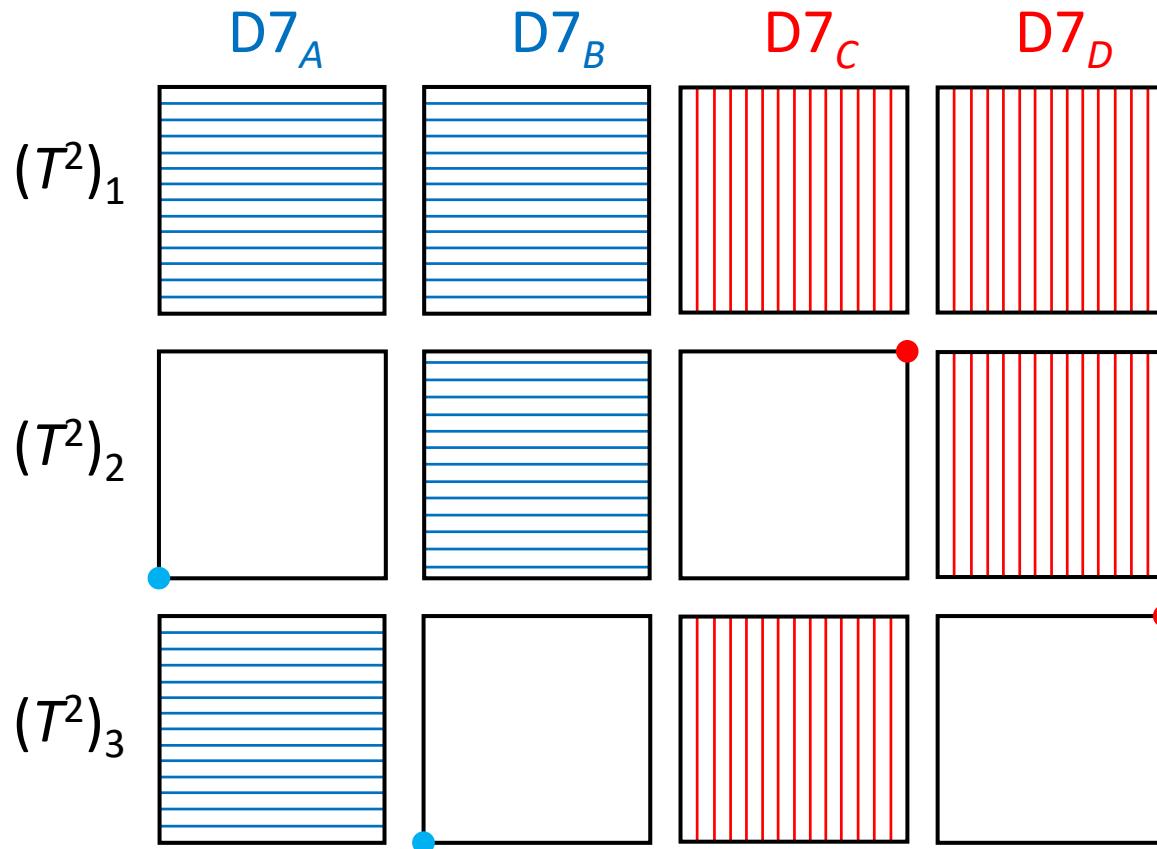
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DSB $N > N_f = 5$ $\hat{M} \equiv Q_N \tilde{Q}_N$

$$W_{\text{DSB}} = g \text{Tr} \tilde{X} \hat{M} + C \left(\frac{\Lambda_N^{3N-5}}{\det \hat{M}} \right)^{\frac{1}{N-5}} \implies \langle \hat{M} \rangle \sim \Lambda_N^2$$

Messenger sector

T. Kobayashi, K. Sumita, S. Uemura & H. A., to appear



No messengers for
gauge mediations
(mainly due to the
parity assignments)



Moduli/anomaly
mediation

Kähler Moduli stabilization

T. Kobayashi, K. Sumita, S. Uemura & H. A., PRD96 (2017) 026019

SUSY (D-flat) condition

$$\mathcal{A}^{(i)} = (2\pi R_i)^2 \operatorname{Im} \tau_i \quad \tilde{R}_i^2 \equiv R_i^2 \operatorname{Im} \tau_i$$

$$\frac{\mathcal{A}^{(1)}}{\mathcal{A}^{(2)}} = \frac{\tilde{R}_1^2}{\tilde{R}_2^2} = \frac{\operatorname{Re} T_2}{\operatorname{Re} T_1} = 12, \quad \frac{\mathcal{A}^{(1)}}{\mathcal{A}^{(3)}} = \frac{\tilde{R}_1^2}{\tilde{R}_3^2} = \frac{\operatorname{Re} T_3}{\operatorname{Re} T_1} = 1$$

fixes the ratio of Kähler moduli

I. Antoniadis, A. Kumar & T. Maillard, NPB 767 (2007) 139

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fixes the ratio of Kähler moduli

I. Antoniadis, A. Kumar & T. Maillard, NPB 767 (2007) 139

Gauge couplings on magnetized D7s

Visible	$\left\{ \begin{array}{l} \text{D7}_A \quad 2\pi f_C = T_2 + 16S = 12T_3 + 16S \\ \text{D7}_B \quad 2\pi f_L = T_3 + 12S \end{array} \right.$
Hidden	$\text{D7}_D \quad 2\pi f_N = T_3 + 12S \quad \frac{1}{g_a^2} = \operatorname{Re} f_a$

Kähler Moduli stabilization

T. Kobayashi, K. Sumita, S. Uemura & H. A., to appear

Configurations of D7-branes

		G	T^2	T^2	T^2	Z_2	Z'_2
MSSM	$D7_A$	$U(4)_A$	✓	✗	✓	$P_A = +\mathbf{1}_4$	$P'_A = +\mathbf{1}_4$
	$D7_B$	$U(4)_B$	✓	✓	✗	$P_B = -\mathbf{1}_4$	$P'_B = -\mathbf{1}_4$
DSB	$D7_C$	$U(1)_C$	✓	✗	✓	$P_C = +1$	$P'_C = -1$
	$D7_D$	$U(N+1)_D$	✓	✓	✗	$P_D = +\mathbf{1}_4$	$P'_D = +\mathbf{1}_4$

Kähler Moduli stabilization

T. Kobayashi, K. Sumita, S. Uemura & H. A., to appear

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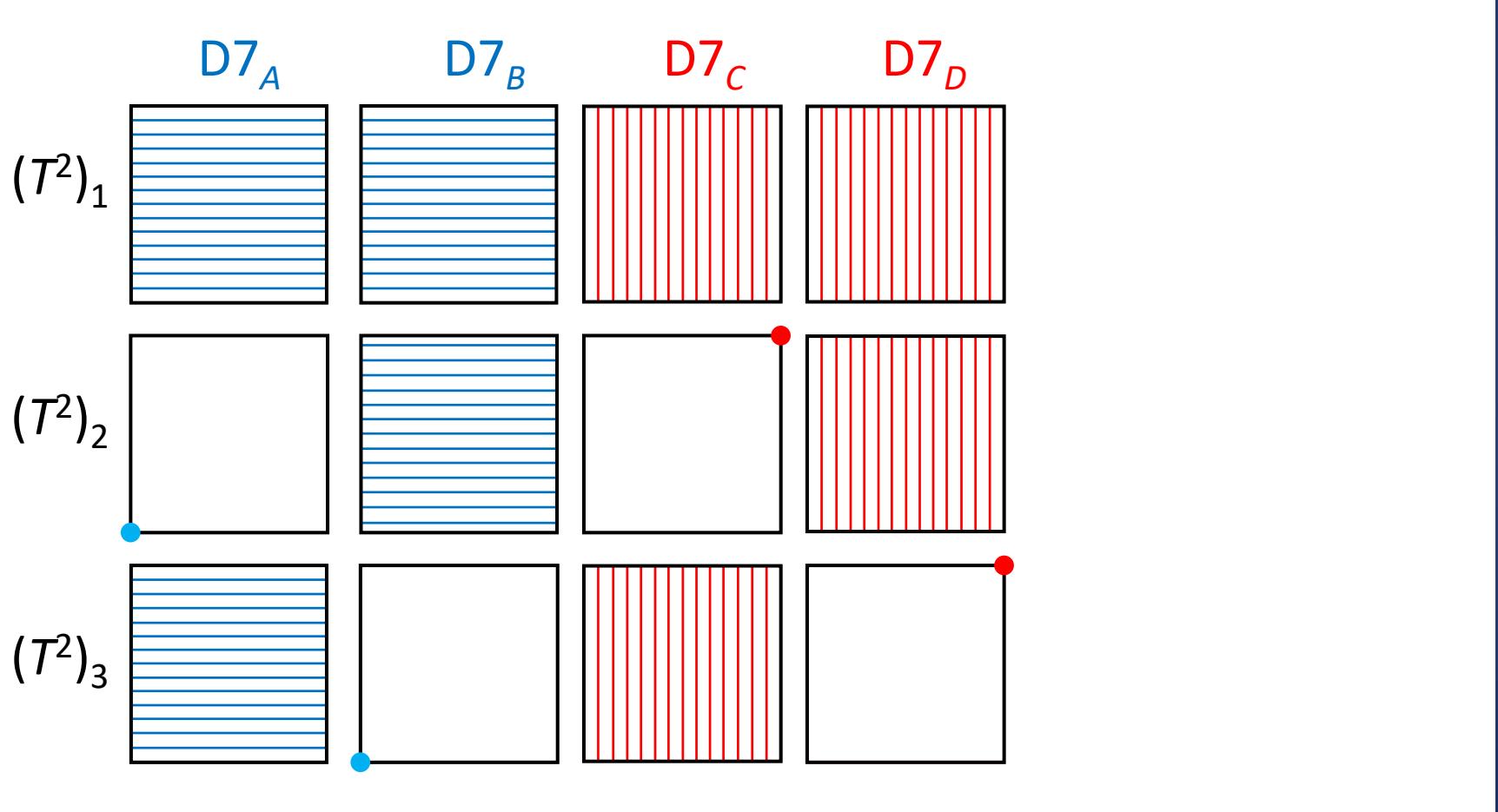
		G	T^2	T^2	T^2	Z_2	Z'_2
MSSM	$D7_A$	$U(4)_A$	✓	✗	✓	$P_A = +\mathbf{1}_4$	$P'_A = +\mathbf{1}_4$
	$D7_B$	$U(4)_B$	✓	✓	✗	$P_B = -\mathbf{1}_4$	$P'_B = -\mathbf{1}_4$
DSB	$D7_C$	$U(1)_C$	✓	✗	✓	$P_C = +1$	$P'_C = -1$
	$D7_D$	$U(N+1)_D$	✓	✓	✗	$P_D = +\mathbf{1}_4$	$P'_D = +\mathbf{1}_4$

E3-brane yielding viable moduli potential

		T^2	T^2	T^2	Z_2	Z'_2
	$E3_E$	✗	✓	✓	$P_E = +1$	$P'_E = +1$

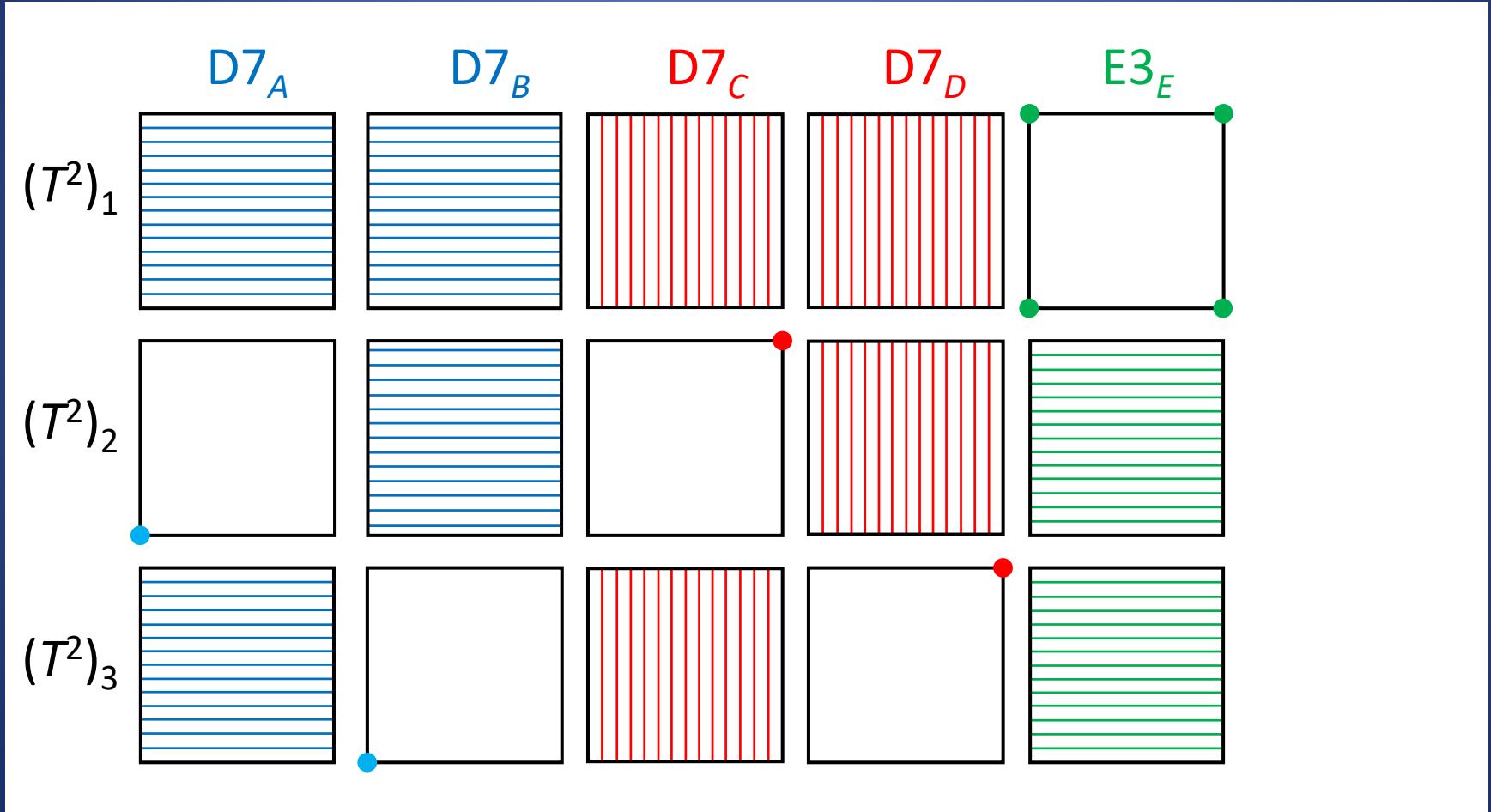
Kähler Moduli stabilization

T. Kobayashi, K. Sumita, S. Uemura & H. A., to appear



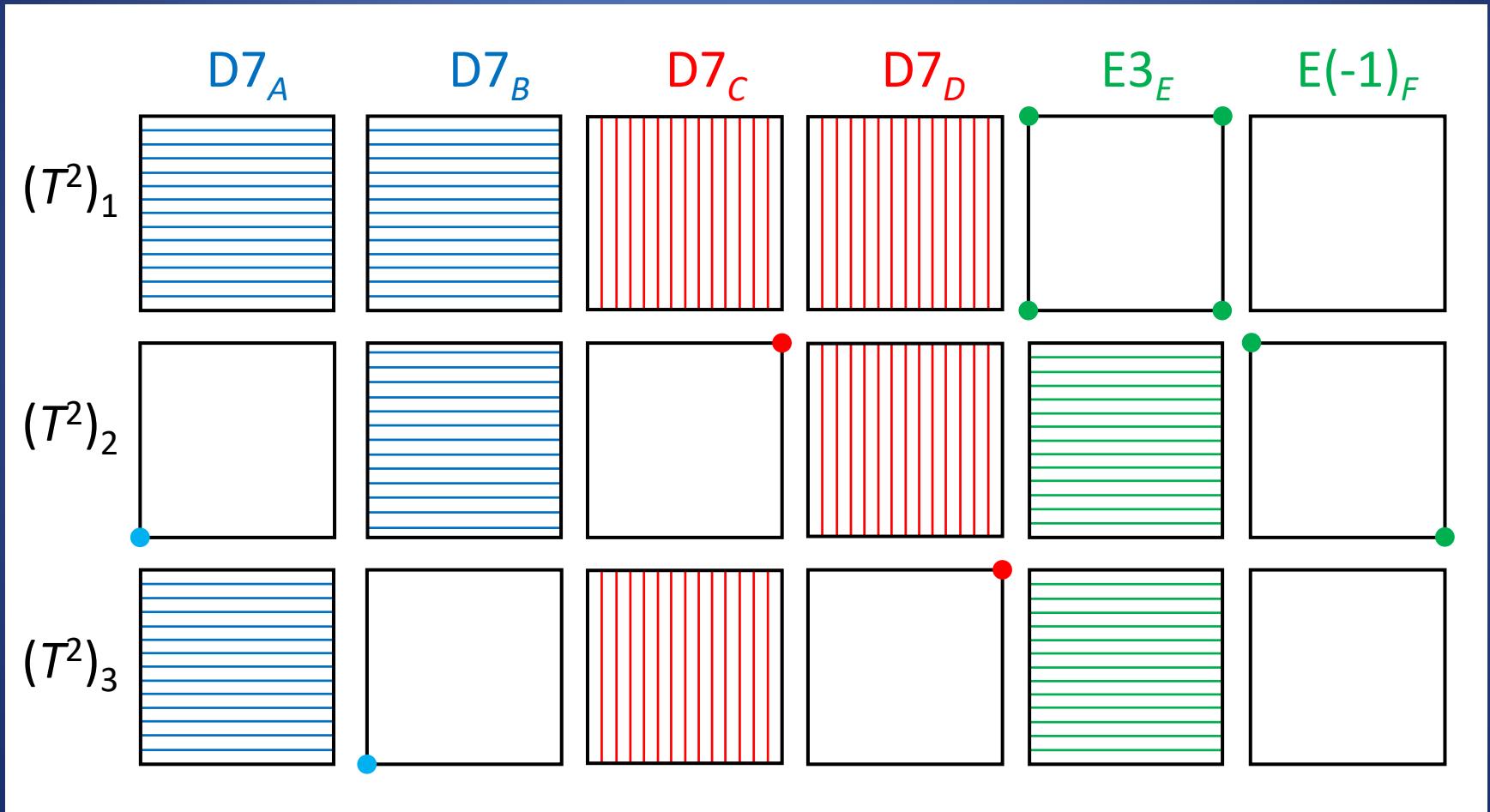
Kähler Moduli stabilization

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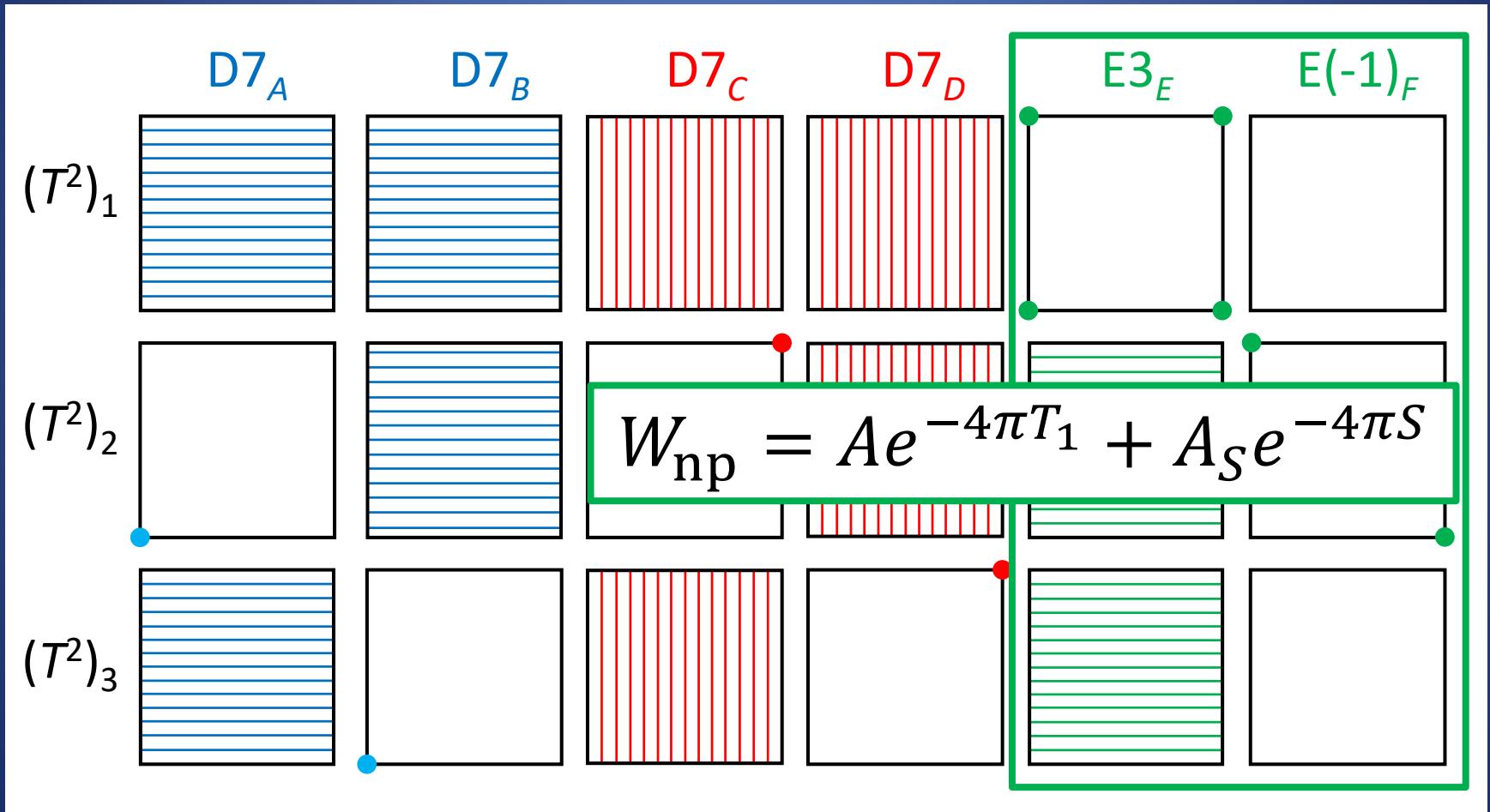
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Kähler Moduli stabilization

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Kähler Moduli stabilization

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Moduli & DSB potential in 4D effective theory

$$K = -\sum_i \ln(T_i + \bar{T}_i) + Z_{X\bar{X}}|X|^2$$

$$\begin{cases} w_0 = A_S e^{-4\pi S} \\ \Lambda_N = M_c e^{-\frac{8\pi^2}{|b_N|} \text{Re} f_N} \end{cases}$$

$$W = w_0 + A e^{-4\pi T_1} + \tilde{B} \Lambda_N^2 X$$

$$2\pi f_N = T_3 + 12S$$

$$b_N = N_f - 3N$$

Kähler Moduli stabilization

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$$b_N = N_f - 3N$$

(Assume three-form fluxes stabilize S and U at a high scale)

Kähler Moduli stabilization

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Moduli & DSB potential in 4D effective theory

$$K = -\sum_i \ln(T_i + \bar{T}_i) + Z_{X\bar{X}}|X|^2 \quad \left\{ \begin{array}{l} w_0 = A_S e^{-4\pi\langle S \rangle} \\ \Lambda_N = M_c e^{-\frac{8\pi^2}{|b_N|} \text{Re} f_N} \end{array} \right.$$

$$W = w_0 + A e^{-4\pi T_1} + \tilde{B} \Lambda_N^2 X \quad \begin{aligned} 2\pi f_N &= T_3 + 12\langle S \rangle \\ b_N &= N_f - 3N \end{aligned}$$

(Assume three-form fluxes stabilize S and U at a high scale)

Single light modulus T in D-flat directions

$$T_1 = \frac{12}{17} T + (\text{heavy modes}), \quad T_3 = \frac{12}{17} T + (\text{heavy modes})$$

Moduli stabilization and F-term uplifting

T. Kobayashi, K. Sumita, S. Uemura & H. A., to appear

Effective superpotential for the light modulus T

$$W = w_0 - Ae^{-aT} + Be^{-bT-c\langle S \rangle} X$$
$$a, b, c \lesssim \mathcal{O}(10)$$

T. Higaki, T. Kobayashi & H. A., PRD76 (2007) 105003

Moduli stabilization and F-term uplifting

T. Kobayashi, K. Sumita, S. Uemura & H. A., to appear

Effective superpotential for the light modulus T

$$W = w_0 - Ae^{-aT} + Be^{-bT-c\langle S \rangle} X$$

$$a, b, c \lesssim \mathcal{O}(10)$$

If $\langle S \rangle \simeq \mathcal{O}(1)$ is stabilized s.t. $w_0 \simeq Ae^{-aT_0} + Be^{-bT_0-c\langle S \rangle}(1 - X_0)$

we find a Minkowski minimum at

$$T_0 \simeq \frac{1}{a-b} \log \left[\frac{aA}{bB e^{-c\langle S \rangle} X_0} \right] \simeq \frac{c}{a-b} \langle S \rangle, \quad X_0 = \sqrt{3} - 1$$

determined by $\partial_X V|_0 = V|_0 = \partial_T W|_0 + (\partial_T K)W|_0 = 0$

T. Higaki, T. Kobayashi & H. A., PRD76 (2007) 105003

Moduli stabilization and F-term uplifting

T. Kobayashi, K. Sumita, S. Uemura & H. A., to appear

Gravitino mass

$$m_{3/2} \simeq M_p^{-2} B e^{-bT_0 - c\langle S \rangle} \quad \text{at the minimum}$$

T. Higaki, T. Kobayashi & H. A., PRD76 (2007) 105003

Moduli stabilization and F-term uplifting

T. Kobayashi, K. Sumita, S. Uemura & H. A., to appear

Gravitino mass

$$m_{3/2} \simeq M_p^{-2} B e^{-bT_0 - c\langle S \rangle}$$

Mass & F-term of the light modulus T

$$\left\{ \begin{array}{lcl} m_T & \simeq & \frac{ab}{3} (T_0 + \bar{T}_0)^2 \left(1 - \frac{b}{a}\right) X_0 m_{3/2} \simeq (4\pi)^2 m_{3/2} \\ \\ F^T & \simeq & \frac{\sqrt{3} m_{3/2}}{(a-b)X_0} \simeq \frac{m_{3/2}}{4\pi} \end{array} \right.$$

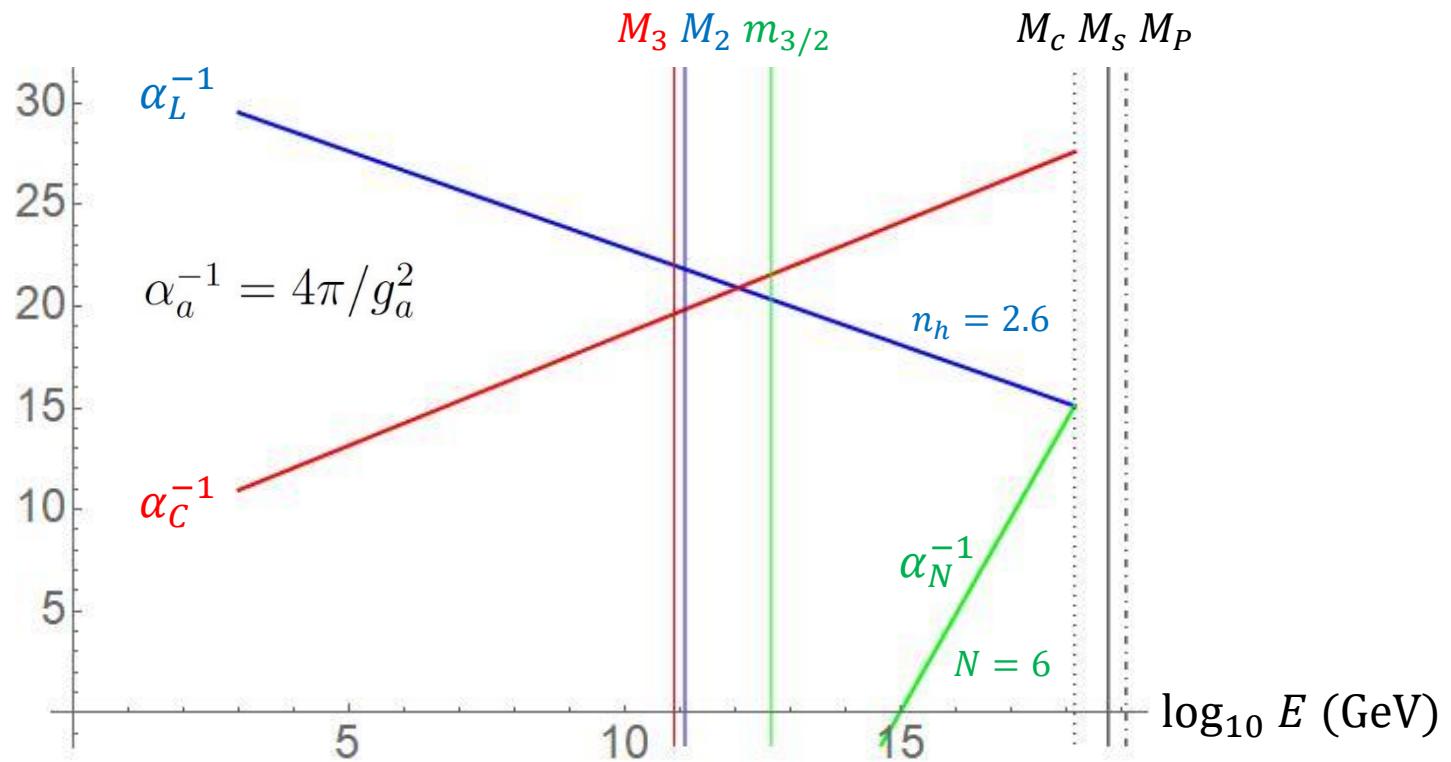
at the minimum

T. Higaki, T. Kobayashi & H. A., PRD76 (2007) 105003

Numerical estimations

T. Kobayashi, K. Sumita, S. Uemura & H. A., to appear

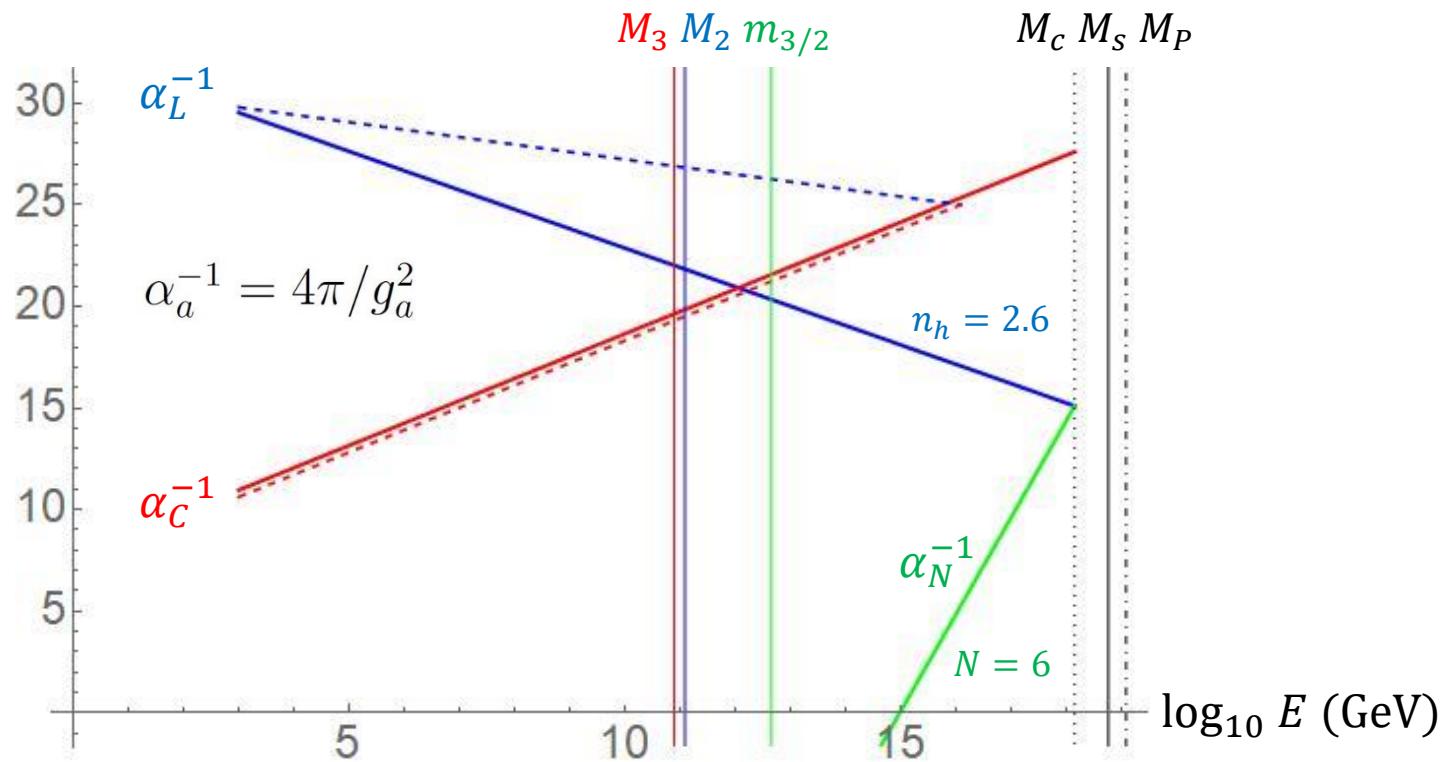
Gauge couplings and scales



Numerical estimations

T. Kobayashi, K. Sumita, S. Uemura & H. A., to appear

Gauge couplings and scales



SUMMARY

Summary and prospects

- Magnetic fluxes would determine almost everything (Gauge syms, chirality, # of gens, hierarchies, DSB, ...) for phenomenology simultaneously
- Kähler moduli will be stabilized by an interplay of fluxed D-term and nonperturbative effects in the semi-realistic D7 models
- The minimum of moduli potential can be uplifted to Minkowski (de Sitter) one by DSB F-term

Summary and prospects

- Further phenomenology/cosmology
 - Inflation in the semi-realistic models?
 - Viable models with gauge mediation?
- Concrete analyses of S and U stabilization by three-form fluxes
 - Cancellation of RR-tadpoles?
 - How much the toroidal background is deformed?